EMBEDDED TRAINING FOR FUTURE FORCE WARRIORS: AN ASSESSMENT OF WEARABLE VIRTUAL SIMULATORS

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ABSTRACT

Embedded virtual simulation has the potential to provide more realistic and effective training for dismounted Soldiers, particularly in operations in urban areas, and in the operation and tactics, techniques and procedures for using Future Force systems. This paper describes an assessment of wearable virtual simulators (WSs) for Infantry Soldiers. The assessment focused on the capabilities and limitations of the WSs as they were used by Soldiers in a realistic training situation: the capability to support the performance of Soldier tasks, side effects, and human interface issues. Three vendors developed different WSs. Each was based on the Quantum 3D Thermite wearable computer, but the vendors used different software and interface hardware. Each permitted a Soldier to view a simulated virtual environment and to interact with other simulated and real entities within it. The SVS, an immersive but non-wearable 3D virtual simulator was used for comparison purposes and to provide enough simulators to fill out a full Infantry squad. OneSAF TestBed was used to provide a simulated enemy force and civilians. Six WS, four SVSs, the Dismounted Infantry Virtual After Action Review System (DIVAARS), and OneSAF were networked to provide a collective training situation in a shared environment. Squads of Soldiers each participated in a series of simulated tactical exercises using the simulators. They then completed questionnaires to report simulator sickness symptoms and to rate the ease with which they could perform 54 Soldier tasks in the simulator. The WSs were able to connect with each other and the SVSs. The major drawbacks to the use of WSs for training appear to be the current lack of graphic processing power of the Thermite computer. Reliability was also a problem. The activities that Soldiers reported they could perform well did not differ substantially from those reported previously with the SVS. The more highly rated tasks consisted of identification of types of people and tactically significant areas, imprecise movement, and communication. The lower rated tasks consisted of precise or rapid movement, distance estimation, and locating the source of enemy fire using either visual or auditory cues. Most of the problems identified should be correctible in the near term.

1. INTRODUCTION

Embedded training is seen as the centerpiece of Future Force Warrior (FFW) and Land Warrior (LW) training. Because of its importance, multiple Army organizations are conducting research and development to enhance its capabilities and effectiveness. The Embedded Training for Dismounted Soldier Science and Technology Objective (STO) is a Research, Development, and Engineering Command Simulation and Training Technology Center (RDECOM STTC) program to develop and evaluate simulation applications for dismounted Soldiers using mobile hardware platforms. The products of the effort include demonstration versions of wearable virtual simulators (WSs) for Infantry Soldiers developed by multiple vendors. The WSs are based on the Thermite wearable computer and are functionally similar to the existing immersive AIS Soldier Visualization Station (SVS). In a related but independent effort, the Army Research Institute for the Behavioral and Social Sciences (ARI), under their Training Future Small Unit Leader and Teams STO, is developing guidelines for what to train, how to train, and how to measure success of training for small unit leaders and teams to take better advantage of FFW capabilities, operational concepts, and tactics, techniques, and procedures. The scope of that effort includes guidelines for the use of new technology for training and performance measurement. In FY 04 an opportunity arose for STTC and ARI to further progress toward their individual research goals by cooperatively conducting an assessment of WSs for small unit and leader training.

Report Documentation Page		*Form Approved* *OMB No. 0704-0188*

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **00 DEC 2004**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**	
4. TITLE AND SUBTITLE **Embedded Training For Future Force Warriors: An Assessment Of Wearable Virtual Simulators**		5a. CONTRACT NUMBER	
		5b. GRANT NUMBER	
		5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)		5d. PROJECT NUMBER	
		5e. TASK NUMBER	
		5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U.S. Army Research Institute for the Behavioral and Social Sciences Orlando, FL 32826-3276; U.S. Army Research, Development, and Engineering Command Orlando, FL 32826-3276**		8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)	
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release, distribution unlimited**			
13. SUPPLEMENTARY NOTES **See also ADM001736, Proceedings for the Army Science Conference (24th) Held on 29 November - 2 December 2005 in Orlando, Florida. , The original document contains color images.**			
14. ABSTRACT			
15. SUBJECT TERMS			

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT **UU**	18. NUMBER OF PAGES **8**	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**			

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Small unit leaders and Soldiers of the Future Force will operate in highly complex decision environments with technological tools and information capabilities never before available. These technologies (e.g., wearable computers, global positioning system, and digital displays) will meet their promise to provide revolutionary advances in small unit effectiveness only if users can be trained to take full advantage of the new capabilities and operational concepts. Soldiers and leaders will need to be trained in both the operation of the equipment and in the tactics, techniques and procedures for using it. Embedded virtual simulation for dismounted Soldiers has the potential to meet this Army training needs. It can also provide more realistic and effective training for combat Soldiers, particularly in those skills required for operations in urban areas. While the Close Combat Tactical Trainer (CCTT) has been fielded to provide training for Soldiers fighting from within vehicles, Soldiers who fight on the ground, such as Infantry and Special Operations Forces, do not have a comparable training capability. Thus while research conducted over the last decade has led to technical advances in Virtual Environments (VE) technology applicable to Soldier training (Campbell, Knerr, and Lampton, 2004), there has been little progress in actually making the technology available to the Soldiers who need it.

Given the constraints on the size, weight, and power requirements of the FFW system, it may never be able to function as a high-fidelity training delivery system for small unit tactical training. However, it is possible that surrogate FFW systems, WSs which mimic the size and weight of the actual FFW systems, but have different capabilities, could be used to deliver both individual and collective training. In order to investigate this possibility further, the STTC contracted with three vendors to develop initial versions of WS. STTC considered it important to get feedback from Soldiers as early in the development process as possible in order to measure progress and set priorities for future development.

This paper describes the conduct and results of the initial Soldier assessment conducted to meet that goal. The objective of the research was to assess the capabilities and limitations of the WSs as they were used by Soldiers in a realistic training situation. It focused on the capability of the WSs to support the performance of Soldier tasks, the severity of side effects (e.g., simulator sickness), and human interface issues. It did not include training effectiveness, which is highly dependent on factors other that the simulators themselves, such as the appropriateness of the scenarios for the skill level of the trainees, and the quality of the After Action Review (AAR).

2. SOLDIER SIMULATORS AND SUPPORTING SYSTEMS

Three vendors (Quantum 3D, General Dynamics, and Advanced Interactive Systems) developed different versions of a WS. Each was based on the Quantum 3D Thermite wearable computer (see Figure 1). The Thermite is a man-wearable tactical visual computer that features a low-power mobile CPU (Transmeta Crusoe 5800 1GHz+ with 512 Kb L2 Cache), 512 Mb DDR memory, an embedded graphics system equipped with an NVIDIA GEForceFX GO 5600 graphics processing unit, and a 20 Gb hard disk drive.

Figure 1. The Thermite wearable computer.

While the vendors designed their systems independently, the resulting systems had many common components and features. Each
- Used the Windows XP operating system.
- Used the 802.11b protocol to communicate with the other systems over a wireless network.
- Included an actual demilitarized M4 rifle or a mock M4.
- Included a combination joystick and pushbutton device mounted on the weapon for control of movement.
- Used multiple sensors to track head, body, and weapon position and orientation.
- Used a bi-ocular or binocular helmet-mounted display (HMD) to present the virtual environment to the Soldier.
- Used an audio headset and microphone to present environmental sounds and voice communications.
- Packaged the system in or on a vest or harness worn by the Soldier.

The AIS system is called the SVS2-DI. The Soldier's viewing device is the IO Display Systems I-Glasses HMD (800 X 600 resolution). All operating systems and SVS2-DI displays are rendered on the HMD. A tracker on the HMD provides information to the SVS2-DI system about the position and orientation of the HMD. A harness-

mounted sensor controls body orientation in the virtual environment, and a weapon-mounted tracker controls weapon orientation in the virtual environment. Therefore, Soldiers can control their eye point gaze direction by orienting their head, their body orientation in the virtual environment by turning their body, and their virtual weapon orientation by aiming their actual weapon in the real environment. The SVS2-DI software user interface can be controlled by using a USB joystick repackaged for mounting on the M4 rifle modular rail system. This joystick is packaged as one unit containing push buttons, a trigger button, a joystick and a control board inside a standard ammunition clip. The Soldier controls movement through the virtual environment, weapon firing, and various SVS2-DI features/modes through this interface. Audio cues are presented to the Soldier via headphones on the HMD. Voice-over IP (VoIP) is available to the Soldier via the microphone on the headset. SVS2-DI software uses the Distributed Interactive Simulation (DIS) 2.0.4 protocol and the High Level Architecture (HLA) to communicate simulation information over the wireless network.

Figure 2. The SVS2-DI

The General Dynamics WS is called the Advanced Soldier Wearable Embedded Training System (ASWETS). It uses the General Dynamics ModIOS® exercise management software packages to provide the network interface to the simulation, exercise control functions, 2D and 3D views, voice communications and exercise recording. It works in conjunction with computer generated forces (CGF) packages and other DIS/HLA simulators. It is interoperable with ModSAF, OneSAF Test Bed (OTB), and any IEEE DIS simulation. ModIOS® Voice Communicator allows the user to transmit and receive radio communication on a simulation network.

The IO Display Systems I-Glasses HMD (800 x 600 resolution) is the primary viewing device for the system.

By looking through the HMD, the Soldier is able to look around in the virtual database, see on-screen overlays and graphics, and interact with other combatants, simulators, and SAF entities provided they are compatible with the simulation protocol (DIS). The embedded stereo headphones enable the Soldier to hear 3D environmental sound effects (weapon fire, explosions, engine noise) and radio communications. The Soldier can transmit voice either by using VOX mode or using push to talk. Three Ascension 6-Degree-of-Freedom sensors track rifle, HMD, and body orientation. Soldiers control their view of the virtual environment by turning their head and/or their bodies in the direction they wish to view. Sensors located on top of the HMD track the orientation, pitch, and roll of the Solder's head. In addition, a leg sensor strapped to the lower thigh provides input on whether the user is standing, kneeling, or prone. A third sensor attaches to the mock weapon to provide weapon position and orientation information. This allows the Soldier to put the weapon out in front of him and see the simulated weapon in the scene. The Soldier moves in the virtual environment by using the joystick located on the mock weapon. It allows the user to move forward, backward, and strafe left or right. A Soldier merely rotates their body in the direction they wish to move to modify their heading. In addition, a Weapons Unit Interface provides several buttons to toggle on various graphical displays, fire weapon, change weapons, boresight sensors, etc. Pulling on the actual weapon trigger fires virtual rounds. To reload the simulated weapon one needs to release and reload the actual clip.

Figure 3. A Soldier wearing the ASWETS.

The Quantum3D WS is called DAGGERS (Distributed Advanced Graphics Generator and Embedded Rehearsal System). DAGGERS uses two Quantum 3D software systems. LightSpeed is ground based real-time image generation software. It provides the system with a rendering engine and a software interface to the motion trackers and input control devices. SoftStealth is DIS interoperable software. It communicates with the DIS network over the wireless interface, maintains a current snapshot of the DIS network state, and controls the virtual environment external to the Soldier Station user.

The Soldier's viewing device is the TekGear Spectre HMD (800 X 600 resolution). All operating systems and LightSpeed displays are rendered on the HMD. Three Intersense InertiaCube2 Orientation Sensors are used to track weapon orientation, HMD orientation, and body orientation. Soldiers can control their view in the virtual environment by turning their head and/or their bodies, and kneeling, standing, or going prone. The helmet mounted motion tracker and the weapon motion tracker are used to determine the user views in the virtual environment.

Soldiers can control their weapon aiming in the virtual environment by aiming their actual weapon in the real environment. The weapon mounted tracker (in combination with the helmet mounted tracker) controls their weapon orientation in the virtual environment. In order to aim thru the weapon's sights the users must rest the side of their face on the weapon stock, mimicking the aiming motion of actual Soldiers when aiming thru a weapon sight. Soldiers can maneuver thru the virtual environment using the weapon mounted controller. This device has a joystick that can be used to move the Soldier forwards and back by pushing the joystick in the up or down direction (relative to the up-down axis of the M4A1 weapon). Soldiers turn left or right by rotating their bodies (or their heads) in the real world. They press the joystick left or right (again relative to the left-right axis of the M4A1 weapon) to move (slide) left and right in the virtual world. Audio cues are presented to the users via the headphones that are part of the Helmet Sub-assembly.

Two other simulators were also used as part of the assessment. They served two purposes. First, they brought the total number of simulators used to nine, sufficient to run scenarios with a full Infantry squad. Second, since they were relatively mature technology, they provided us with a basis for comparison. The Solider Visualization Station Stand-up (SVSS) is an immersive but non-wearable 3D virtual simulator. The SVSS is shown in Figure 5. The SVSS uses a rear-screen projection system to present images (800 X 600 resolution) on a screen approximately 10 feet wide by 7.5 feet high. The Soldier's head and weapon are tracked using an acoustic tracking system. The Soldier navigates through the environment via a thumb switch located on the weapon. The SVS was developed by AIS and is very similar, in terms of software functionality, to the SVS2-DI. The second non-wearable simulator, the SVS Desktop (SVSD), is also functionally similar to the SVSS. The Soldier sits at a PC and views the simulation on an LCD monitor. A joystick is used to control movement and weapons use. The SVSS and SVSD have been in use and undergoing frequent updates at the Soldier Battle Lab, Fort Benning, for approximately six years.

Figure 4. A Soldier wearing DAGGERS.

Figure 5. The SVSS

OneSAF Testbed software was used to provide a simulated enemy force and civilians. The Dismounted Infantry Virtual After Action Review System (DIVAARS) was used to record exercise data and to
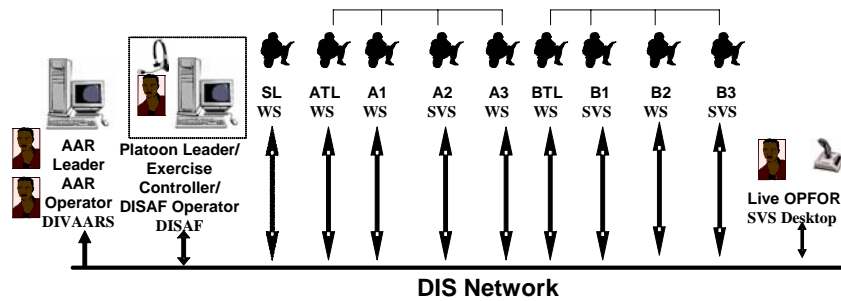
Figure 6. Conceptual configuration of the simulators and supporting systems.

Support After Action Reviews (Knerr, Lampton, Martin, Washburn, & Cope, 2002). All simulators, DIVAARS, and OneSAF were networked to provide a collective training situation in a shared environment. Up to six WSs (two AIS, three Q3D, and one GD) and three SVSs (two standup and one or more desktops) were used. See Figure 6.

3. METHOD

The assessment was conducted in the Soldier Battle Lab, Fort Benning, GA during July 2004. Four squads of nine Soldiers each participated in a series of simulated tactical exercises. Two squads participated for two days each and two participated for one day each. There were a total of 36 Soldiers involved. These were a mix of Infantry School instructors and students awaiting the start of a class. Their pay grades ranged from E-2 to E-6. The most significant characteristics of this group of Soldiers were that they were not intact squads of Soldiers used to working together, and many, particularly the NCOs, had recent combat experience.

Each group of soldiers was expected to report for two days. On the first day, they would be trained in the use of a simulator, given an opportunity to practice using that simulator, and then conduct four training exercises. After completing each exercise, they would complete a questionnaire to report simulator sickness symptoms. After completing all four exercises, they would complete a questionnaire to rate the ease with which they could perform 54 Soldier tasks in the simulator. On the second day, they would repeat the activities of the first day using a different simulator and, in addition, participate in a group interview to identify the strengths and weaknesses of each type of simulator.

Four different urban operations scenarios were used in the assessment: two assault scenarios and two deliberate attack scenarios. Each took place in a virtual recreation of the Shughart Gordon MOUT site at Fort Polk, LA. Each exercise consisted of the delivery of the operations order to the Squad Leader, a mission planning period, a briefing of the plan to the squad by the Squad Leader, conduct of the mission, and an After Action Review. Each scenario was run twice in succession. The mission briefing and planning periods were abbreviated for the second run.

Two questionnaires were used to obtain information from the Soldiers. The *Simulator Capabilities Questionnaire* was given to each Soldier at the end of each day's training. It includes 54 soldier activities (at the subtask level), such as "maneuver close to others," "identify enemy soldiers," and "fire weapon accurately." Soldiers rate their ability to perform each activity in the simulator on a four-point scale, from *Very Good* to *Very Poor*.

The *Symptom Checklist* is a list of symptoms used to assess simulator sickness. It is a modified version of a checklist developed by Kennedy, Lane, Berbaum, and Lilienthal (1993). Each of 16 symptoms is rated as *None, Slight, Moderate*, or *Severe*. Soldiers completed this questionnaire at the beginning of each day, and once after each use of each simulator. Scoring formulas provide measures of overall severity, and scores on three separate subscales: Oculomotor Discomfort, Disorientation, and Nausea.

4. RESULTS

There were some deviations from the plan. Because of operational requirements, one group of Soldiers failed to return for a second day, and a new group was substituted. We were also unable to implement a voice communication system that would let all Soldiers both hear environmental sounds and have simulated radio contact. A solution was developed that simply placed Solders in close physical proximity (see Figure 7).

4.1. Simulator Capabilities

We first compared the mean rating over all 54 items across all five simulators (three WS, the SVSS, and the

SVSD). The results are shown in Table 1. The means were not significantly different (F=.688, df =4, p=.604). A score of 2.0 corresponds to a verbal rating of "good."

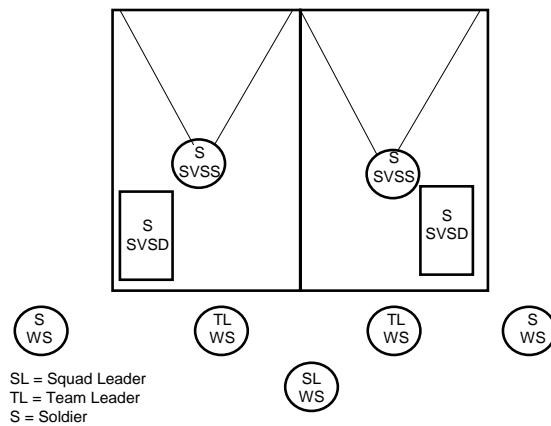Figure 7. Physical configuration of the nine simulators.

Table 1
Mean Simulator Capability Ratings for Each Simulator

Simulator	Mean	Standard Deviation	N
DAGGERS	1.94	.57	13
SVS2-DI	1.84	.22	10
ASWETS	1.86	.18	6
SVSS	2.10	.39	12
SVSD	1.97	.37	13
Overall	1.96	.39	54

Next we compared the overall mean ratings of the WSs with the SVSs (non-wearables). The SVSs had a slightly but non-significantly higher mean (2.03 vs 1.89). Finally, we compared the WS with the non-wearables on each of the 54 individual Soldier activities. Here we found some significant differences. The SVSs were rated significantly (p<.05) higher on the following items:

- *Move according to directions*
- *Manuever around obstacles*
- *Move in single file*
- *Manuever below windows*
- *Determine other team/squad members' positions*
- *Maintain position relative to other team/squad members*
- *Fire weapon in short bursts*
- *Move close to walls*

The WS were rated higher than the SVSs on the item *Scan vertically.*

Since the SSVS was most similar to the WSs, we also compared the socores of the SVSS and the WS on each of the 54 items. The SVSS was rated significantly higher than the WS on the following items:

- *Determine other team/squad members' positions*
- *Visually locate the source of enemy fire*
- *Distinguish between friendly and enemy fire*
- *Fire weapon in short bursts*
- *Move quickly to the point of attack*
- *Determine the direction enemy rounds are coming from*

The WS were rated higher than the SVSS on the item *Scan vertically.*

The ten tasks rated highest and lowest on the WS are shown in Table 2.

Table 2
Highest-and lowest-rated WS tasks

Ten highest-rated WS tasks	Mean	N
Execute planned route.	2.24	29
Identify civilians.	2.21	29
Scan from side-to-side.	2.18	28
Scan vertically.	2.18	28
Locate assigned areas of observation, e.g. across the street.	2.15	27
Locate support team positions.	2.14	28
Identify enemy soldiers.	2.14	28
Move through open areas as a widely separated group.	2.14	29
Identify covered and concealed routes.	2.14	29
Locate fire team buddy positions.	2.12	26

Ten lowest-rated WS tasks	Mean	N
Fire weapon in short bursts.	1.56	25
Climb up or down stairs.	1.56	26
Move close to walls.	1.55	29
Maneuver below windows.	1.54	26
Maneuver past other personnel in a room.	1.50	26
Use fragmentation grenades.	1.46	13
Use flash-bang grenades to help clear rooms.	1.45	11
Move past furniture in a room.	1.38	13
Determine the direction enemy rounds are coming from.	1.37	27
Determine the source of enemy fire by sound.	1.34	29

Precise movement, such as movement in corridors, up stairs and through doorway, tended to be a problem for all simulators, not just the WS.

4.2. Simulator sickness

Mean overall simulator sickness scores are shown in Table 3. These scores were calculated by assigning a score of 1 to each slight symptom, 2 to each mild symptom, and 3 to each severe symptom. The means for the simulators do differ significantly ($F=4.578$, $df=4$, $p=.002$), and this difference is entirely attributable to the difference between the scores for the DAGGERS simulators and the others, which do not differ significantly among themselves. The same pattern remained when we looked at the scores for three different dimensions of simulator sickness, Nausea, Oculomotor Discomfort, and Disorientation: DAGGERS produced higher scores than the others, which did not differ among themselves. The highest scoring symptoms for DAGGERS were eyestrain (.58), general discomfort (.44), headache (.47), difficulty focusing (.35) and blurred vision (.26). This suggests that the visual display system was a causal factor.

Table 3
Simulator Sickness Scores

Simulator	Number of Participants	Number of Cases	Mean Simulator Sickness Score	Median Simulator Sickness Score
DAGGERS	13	43	4.33	2
SVS2-DI	10	36	1.56	0
SVSD	14	46	1.39	0
SVSS	12	43	1.35	0
ASWETS	6	21	1.19	0

4.3. Lessons Learned

- Wireless networking using the 802.11b protocol worked very well. This is a mature technology well suited to this application.
- Safety was not a problem. Soldiers wearing the HMDs see the real world well enough to avoid any obstacles.
- The reliability of the WSs, or lack thereof, was a problem. Battery life, sensors, and connectors were all contributing factors.
- The version of the Thermite computer used has insufficient processing power, particularly graphic processing power. Despite efforts to reduce the number of entities (vehicles and people) in the scenarios, the wearable simulators experienced significant lag and, in some systems, freezes.

- Soldiers liked the HMDs, particularly the ability it gave them to scan horizontally and vertically. On the other hand, they disliked the narrow FOV.
- Movement control was a problem for all systems. Everyone had a system that more or less worked, but each had some problems.
- Inability to do voice communications electronically (ASTi and Voice over IP) was probably the biggest immediate problem. The interim solution worked, but not optimally.
- There were a number of integration issues. Movement rates were not synchronized, so that some simulators moved more rapidly than others .
- The ability to move sideways was one of the most requested features.

5. DISCUSSION

The overall goal of gathering data that would lead to advancements in the state of the art of wearable computers was met. We were able to take the simulators made by three different vendors and interconnect them with existing simulators and support systems. The WSs were successful in placing and maintaining the Soldiers who wore them in the simulated environment. The wireless network worked well. The major drawback to the use of WSs for training appears to be the current lack of graphic processing power of the Thermite computer. Despite the effort to simplify the environment by simplifying the architecture, vegetation, and number of entities (people and vehicles) in the scenarios, the graphic on the WSs lagged and sometimes froze. Reliability was also a problem: battery life was shorter than anticipated, and connectors became disconnected.

In general, the pattern of activities that Soldiers reported they could perform well, and not well, did not differently substantially from that report previously with the SVSS (Knerr et al., 2003). The more highly rated tasks consisted of identification of types of people (such as civilians and non-combatants) and tactically significant areas, imprecise movement, and communication. The lower rated tasks consisted of precise or rapid movement (including aiming), distance estimation, and locating the source of enemy fire using either visual or auditory cues. Generally, precise motion, either body movement in confined areas or weapons aiming, could not be performed as well with the WS as with the SVSs. System lag is probably a major contributing factor. Soldiers did report, however, better vertical scanning with the WS.

Simulator sickness was a problem only with the DAGGERS. DAGGERS users reported significantly higher symptom frequency than did the users of the other systems. We suspect that this was a result of the HMD used. It had a very small exit pupil, which meant that it

had to be precisely positioned on the head. Head movements could cause a temporary loss of the image. It also had an adjustment for inter-pupillary distance, which each Soldier had to make. If this was not done properly, the images seen by the two eyes would not fuse, and eyestrain would result. There was no way to check to see it the adjustment had been made properly. Four of the five most frequent symptoms reported by DAGGERS users involved vision.

Most of the problems identified should be correctible in the near term. With these usability problems corrected, it should be possible to begin to investigate the issue of training effectiveness. How effective are the wearable simulators for training? What skills are they best suited for training (individual or collective, individual or team)? Where do would they best fit into the Army training system, unit or institution? The answers to these questions have implications for FFW and future Army training.

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